National Defense Center for Energy and Environment

Photovoltaic (PV) Power Systems for Enhancing Energy Security

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E2S2, New Orleans

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Outline

- Demonstration Overview
  - Camp Katuu Site Review
  - Camp Katuu Demonstration Goals
- Development and Design Considerations
  - PV Layout Development
  - Component Selection
    - Operating Modes
    - Operating Environment
    - Availability
- System Options
  - Palau PV System Results
  - Alternative Systems to Enhance Energy Security

Site Review

- Camp Katuu, located near Koror, Palau; latitude of 7° 30’ North
- Remote location
  - Fragile local electrical utility powered by diesel generation
  - High electricity costs
- Corrosive environment
- Abundant sunshine

Demonstration Goals

- Camp Katuu Installation
  - Increase civil outreach and nation building with Palau Government
  - Reduce environmental footprint at Camp Katuu
  - Increase use of alternative energy
  - Demonstrate the feasibility of using alternative energy in the region
  - Quantify PV system performance/capability
  - Train 249th Engineer Battalion to install photovoltaic systems
  - Train Palau Civic Action Team to operate and maintain system
  - Validate camp electrical costs reduction
- Future Installations
  - Leverage design aspects for other remote installations (grid frequency and voltage regulation, corrosion, high electricity costs)
  - Next generation to include off-grid operation capability with energy storage

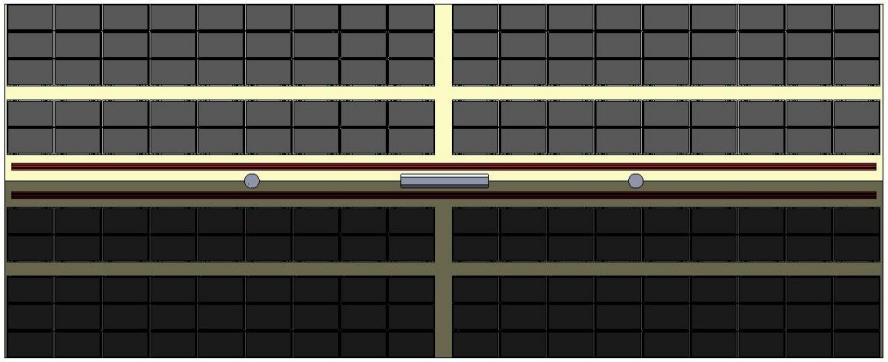
PV Layout Development

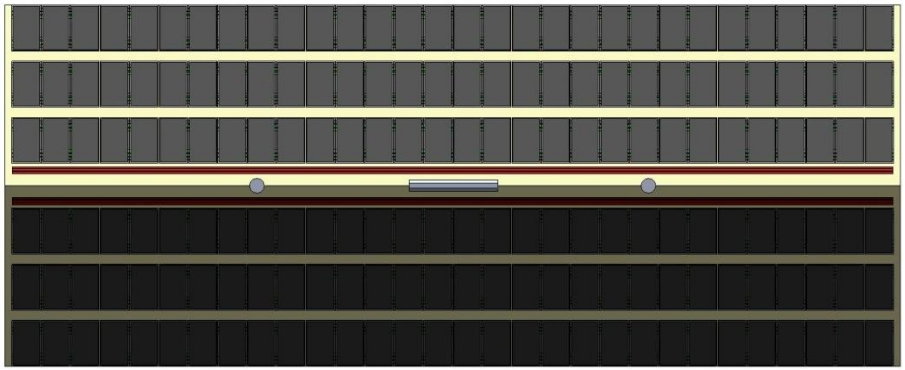
- Sustainability Considerations
  - Safety, maintenance, and reliability
  - Access ways for installation, maintenance, repair
- Performance
  - Simple, intuitive, and robust installation
  - Reliability and electrical costs reduction
  - Roof mounting maximizes capability given limited camp footprint

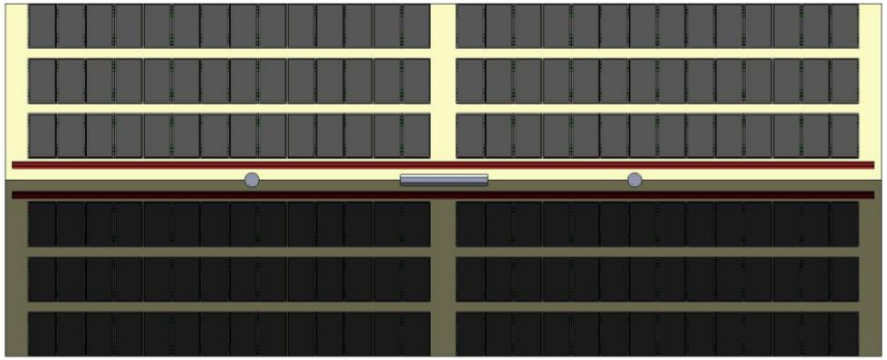
Camp Katuu Builder's Shop – PV Array Installation Location

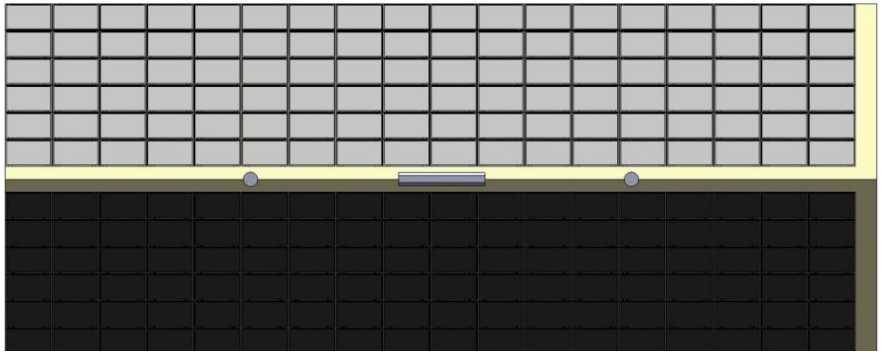
PV Layout Development (cont.)

- PV System Layout Options Considered









PV Layout Development (cont.)

- PV System Layout Considerations and Comparisons

PV LAYOUT OPTION SUMMARY					
		Option 1	Option 2	Option 3	Option 4
No.	Consideration	5 Horizontal Rows	3 Vertical Rows	3 Vertical Rows with Center Walkway	6 Vertical Rows
1	Amount of rail mounting (lf)	1440'	1800'	1800'	1440'
2	Ease of rail installation	some rail cutting required to clear walkway	requires two level rail mounting system	requires two level rail mounting system	no rail cutting required
3	Ease of wiring	Intuitive circuit pattern	Very Intuitive circuit pattern	Very Intuitive circuit pattern	odd circuit pattern
4	Maintenance access	21" horizontal & vertical walkway, does not have direct access to all panels	Accessible with 15" walkways	Direct access to each panel and has a center walkway	No direct access to most panels
5	System DC Rating (kW DC) [1]	42.300	42.300	39.480	50.760
6	System AC rating (kW AC) [2]	32.571	32.571	30.400	39.085
7	Fall Protection System	accomodates rail system	accomodates rail system	accomodates rail system	does not accommodate rail system
8					

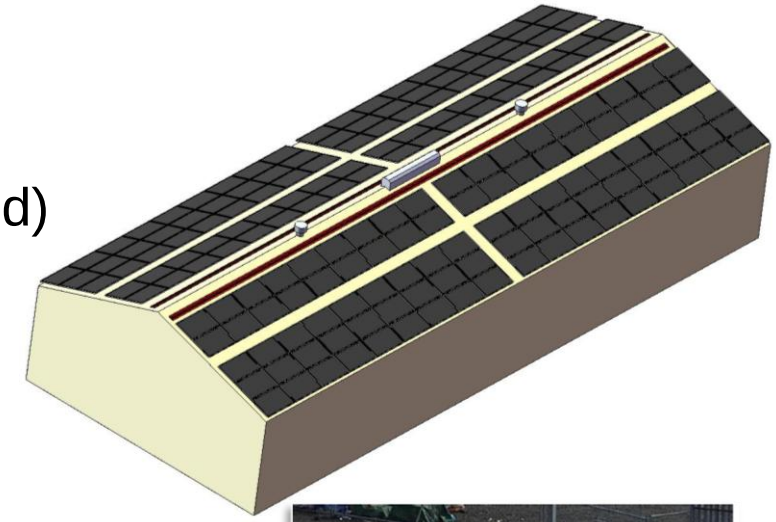
Color Legend
most favorable
more favorable
least favorable

Note [1] System DC Rating based upon use of 235W solar panels

Note [2] System AC Rating based upon typical .77 conversion factor from DC power to AC power

PV Layout Selected – Option 1

- Easiest to Implement and Sustain
  - Safety rails
  - Access ways (beginning to be required)
  - Intuitive circuitry/wiring
- Performance
  - Met power requirements



OPTION 1 CONSIDERATIONS

No.	Consideration	Impact
1	Amount of rail mounting (lf)	1440'
2	Ease of rail installation	some rail cutting required to clear walkway
3	Ease of wiring	Intuitive circuit pattern
4	Maintenance access	21" horizontal & vertical walkway, does not have direct access to all panels
5	System DC Rating (kW DC) [1]	41.400
6	System AC rating (kW AC) [2]	31.878
7	Fall Protection System	accomodates rail system

Color Legend

most favorable
more favorable
least favorable

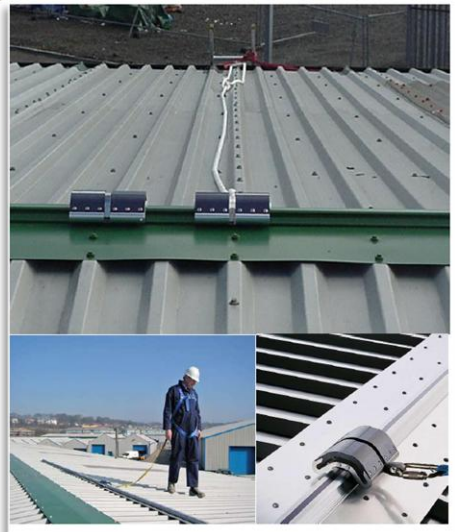


Figure 7: Rail Type Fall Protection System

Component Selection
PV Module

- Best value ($/watt)
- Tested for corrosion
- Stock item
- ***Common Attributes!!***

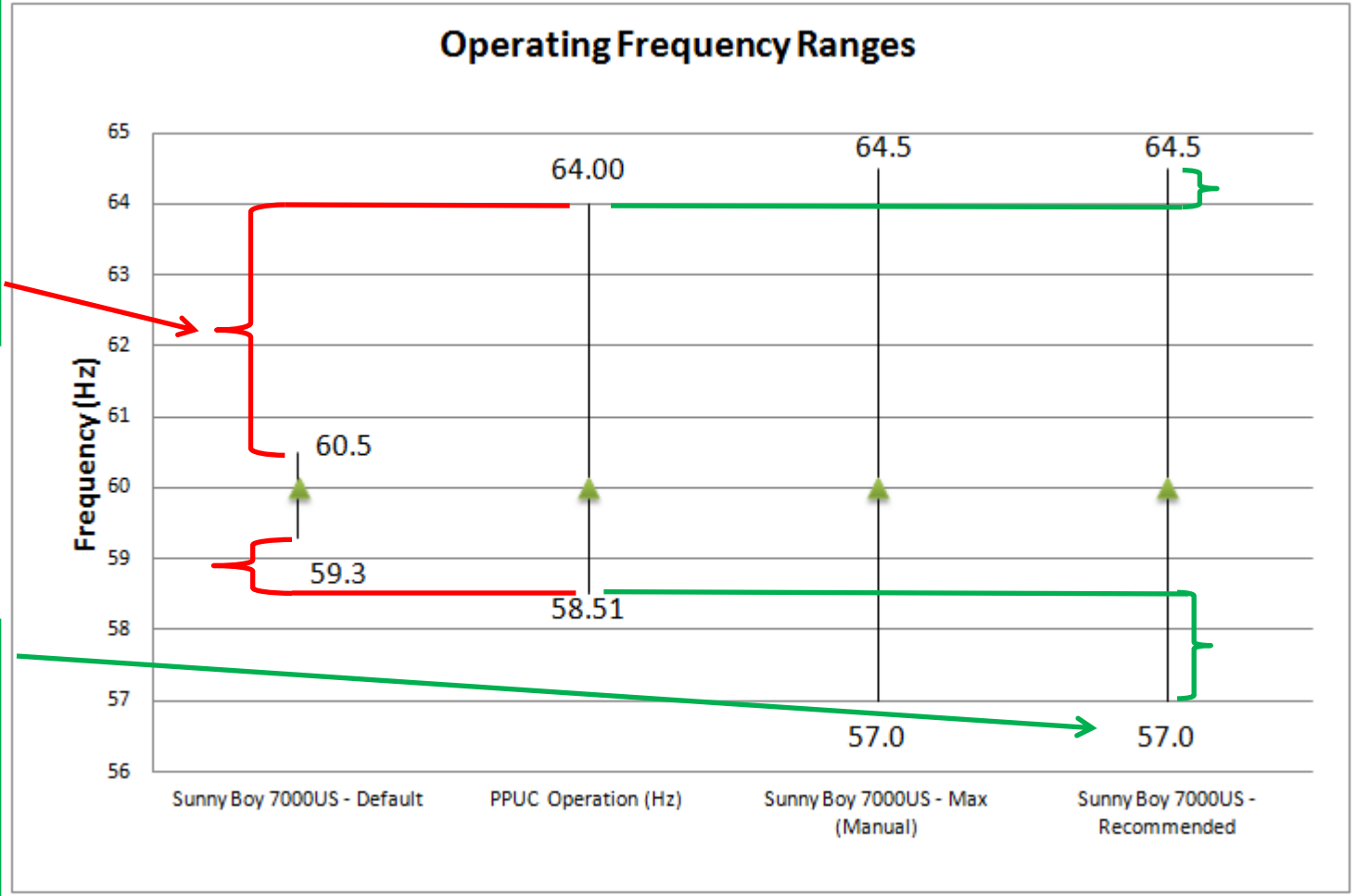
PV Module Specifications	Canadian Solar
Mechanical Attributes	**CS6P-235P**
Length(in)	64.5
Width (in)	38.7
Thickness (in)	1.57
Weight (lbs)	44.1
Electrical Attributes [1]	
Nominal Maximum Power Output at STC (Pmax)	235 Watts
Voltage at Pmax (Vmp)	29.8 Volts
Current at Pmax (Imp)	7.9 Amps
Open Circuit Voltage (Voc)	36.9 Volts
Short Circuit Current (Isc)	8.09 Amps
[1] Standard Test Conditions for panel ratings: 1,000 Watts/M^2, AM 1.5, 25 C	

Component Selection
Inverter

- Six SMA 7000US inverters for ***grid-tied system***
- Reliable product
- Very low maintenance
- Rated for outdoors use
- Simple, informative interface
- Integral DC disconnect
- Stock item
- ***Can accommodate electricity grids with poor voltage and frequency regulation***

Component Compatibility

Issue – Utility upper operating frequency range exceeds inverter default settings; *nuisance trips will occur!!*



Solution – Increase inverter operating frequency range based upon electrical utility operations and input

Default Frequency Operating Range is not compatible

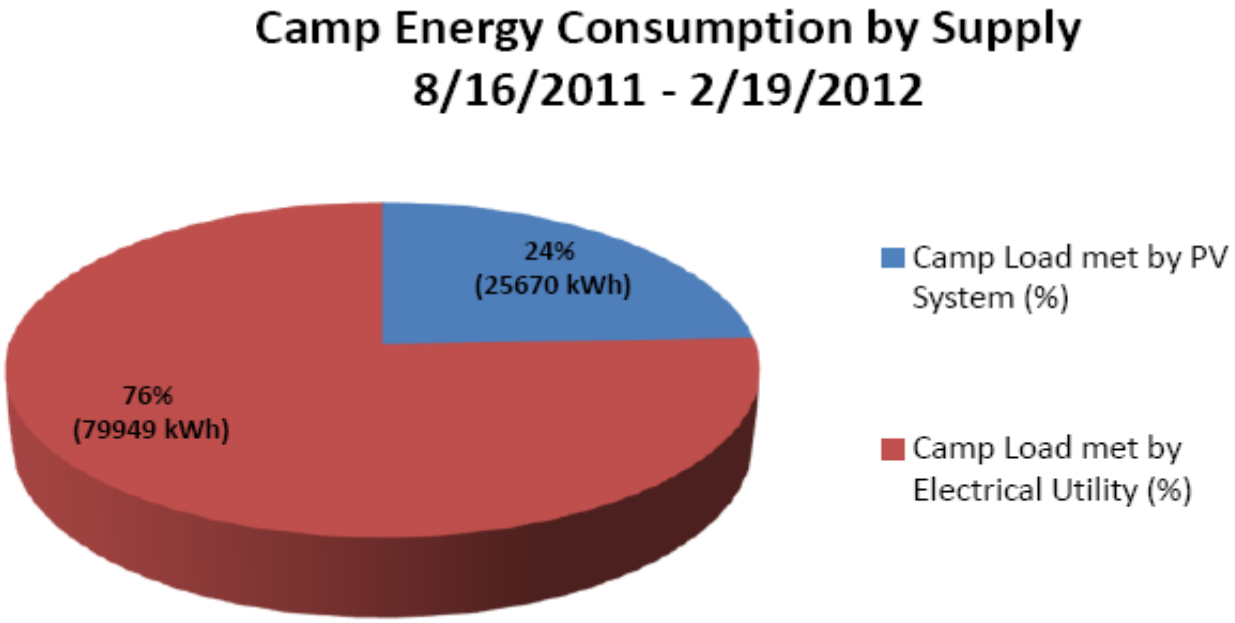
Camp Katuu Results

- Installed by 249th Engineering Battallion (Prime Power) and Camp Katuu Civic Action Team
  - ***All wiring correct per installation drawings***
  - ***Very quick commissioning***

- System Reliability During 6 Month Sustainment Period:
  - ***No failures or repairs***
  - ***System automatically restarted after each grid outage***

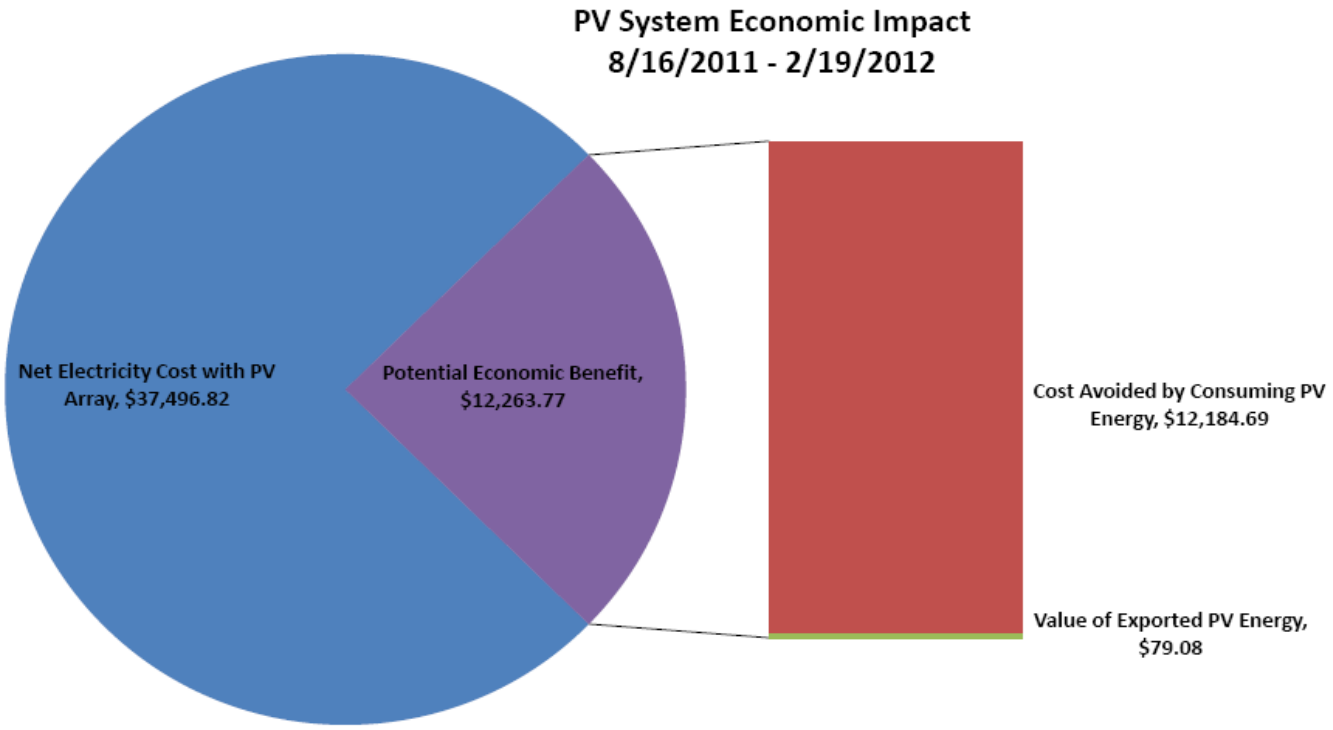
Camp Katuu Results (cont.)

- System Performance During 6 Month Sustainment Period:
  - ***Electrical cost savings exceeded estimates by***
    Adjusted: 17% ($25.5k versus $21.8k annually)
    Actual: 10% ($23.9k versus $21.8k annually)
  - ***Production met expectations, given rainy season, achieving 94% of annual estimate (53.9MWh versus 57.9MWh)***



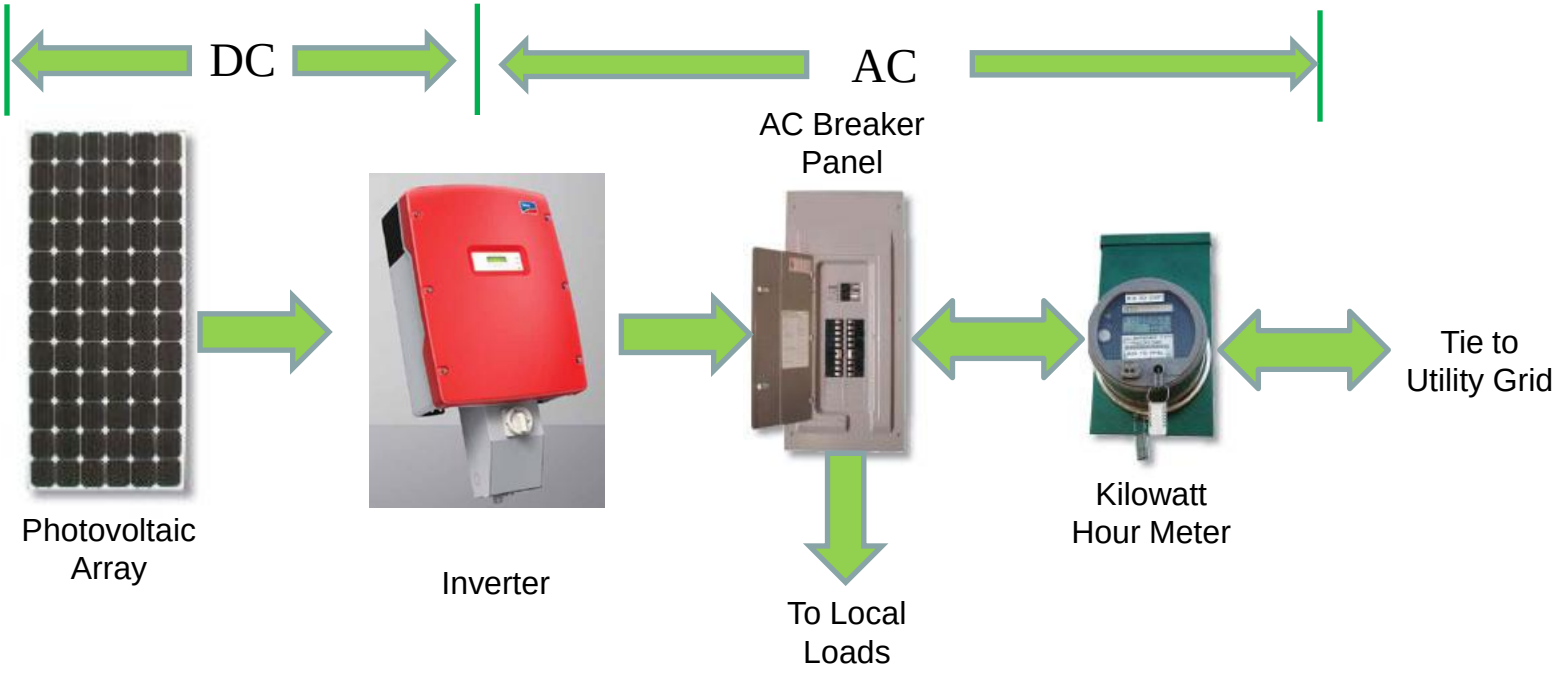
Camp Katuu Results (cont.)

- System Performance During 6 Month Sustainment Period:
  - ***Energy cost estimate without PV array :*** ***$49.8k***
  - ***Energy cost with PV array:*** ***$37.5k***
  - ***Camp energy cost reduction by PV array:*** ***25%***



System Options

- Grid - Tied System
  - Camp Katuu System

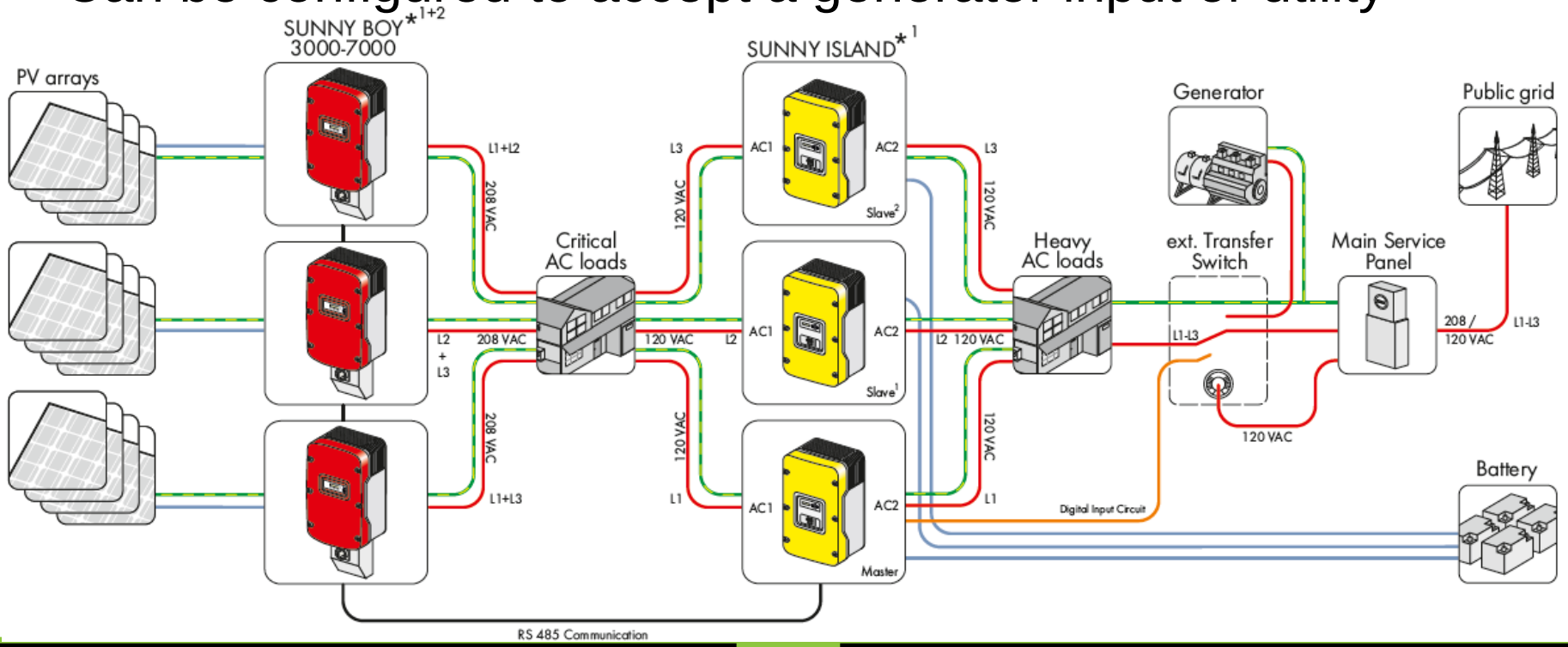


Alternative Systems to Enhance Energy Security

- Grid - Tied System
  - Key Benefits
    - Simple to install
    - Easy to maintain
    - Reduces electrical costs
    - Grid can serve as a load for exporting excess renewable energy
    - Very sustainable
  - Key Considerations
    - Requires grid to operate
    - Very few products compatible with unstable grids

SMA's Sunny Island

- Major Components:
  - Battery bank w/ monitoring
  - Sunny Island
- Can be configured to accept a generator input or utility



SMA's Sunny Island

- Island System - SMA
  - Leverages multiple energy sources
    - Wind, solar
    - Battery bank
    - Generator or utility
  - Key Considerations
    - Not intended for export
    - Number of components to build system
    - Desired system voltage:
      - Single phase 120/240VAC
      - Three phase 120/208, 277/480

Outback's Radian Inverter

PV Array

Charge Controller

DC Charge/ Discharge

AC Generator

Utility Source

Energy Storage

DC Bus

Critical Loads

System Options

- Hybrid System - Outback
  - Leverages Multiple Energy Sources
    - Solar
    - Battery bank, bi-directional
    - Generator
    - Utility
    - Can export
  - Key Considerations
    - Must meet UL1741 for export
    - 120/240 VAC rated system

Summary

- Power Systems to Enhance Energy Security Include:
  - Grid - Tied: simple, few components, no off-grid support
  - Off - Grid: simple, more components than off-grid, requires energy storage
  - Hybrid Systems: few options, but can leverage numerous energy resources to achieve energy security

Questions?

Palau PV System Ribbon Cutting Ceremony Celebrating:

Nation building through the successful implementation of renewable energy systems

Left to right: **Ambassador Helen Reed-Rowe, SFC Daniel Husak, 1st Lt Melissa Jumper, LCDR Grant Watanabe, Clark Boriack (CTC Technical Lead)**

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